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CHAPTER TWENTY-SIX

DIETARY TRENDS AT THE MESOLITHIC– NEOLITHIC TRANSITION IN NORTH-WEST EUROPE

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Abstract

Empirical and model data are used to re-assess the patterns of dietary change across the Mesolithic–Neolithic transition in north-west Europe. A step-shift in bone collagen $\delta^{13}\text{C}$ values can be observed among coastal populations in Great Britain and parts of southern Scandinavia c. 4000/3900 cal BC, reflecting the rapid introduction of farming. Regional and local variations are evident, and there is a clear geographical trend in the use of marine resources by Neolithic populations across north-west Europe. Our findings suggest that the $\delta^{13}\text{C}$ value of bone collagen may not accurately reflect the proportion of seafood in a diet where the diet included significant quantities of marine bivalves, such as oysters. This also has implications for calculating the marine reservoir contribution to the ^{14}C ages of human bones.

Résumé

Des données empiriques et théoriques ont été utilisées pour réévaluer l'évolution et les changements alimentaires durant la transition Mésolithique–Néolithique dans le nord-ouest européen. Un brusque changement des valeurs $\delta^{13}\text{C}$ du collagène osseux est observé parmi la population côtière de la Grande-Bretagne et dans certaines parties du sud de la Scandinavie vers 4000/3900 cal

BC, reflétant la rapide introduction de l'agriculture et de l'élevage. Les variations locales et régionales sont évidentes comme la nette variation géographique de l'utilisation des ressources marines par les populations néolithiques du nord-ouest de l'Europe. Nos résultats suggèrent que la valeur $\delta^{13}\text{C}$ du collagène osseux pourrait ne pas refléter, de façon précise, la proportion de fruits de mer du régime alimentaire quand celui-ci comporte une quantité importante de bivalves marins, comme les huîtres. Ceci a aussi une importante conséquence dans le calcul de la contribution du réservoir marin dans l'âge ^{14}C des os humains.

Keywords: *palaeodiet, stable isotopes, Mesolithic, Neolithic, north-west Europe*

Mots-clés: *régime alimentaire, isotopes stables, Mésolithique, Néolithique, nord-ouest de l'Europe*

1. Introduction

This paper is concerned with the transition to farming in two key regions of north-west Europe, Great Britain and southern Scandinavia, and specifically with the evidence provided by stable isotope analysis of human bone collagen. The first traces of agriculture and the Neolithic are found in both regions c. 4000/3900 cal BC after a lengthy period when the agricultural frontier stabilized to the south across the North European Plain extending westwards to the Channel coast of northern France.

In Britain, the prevailing view during the 1980s and 1990s was that the transition was gradual, with farming being slow to replace hunting and gathering as the primary mode of subsistence (e.g. Thomas 1991; Armit and Finlayson 1992; Whittle 1999). However, with the widespread application of stable isotope analysis and AMS dating of human remains a different interpretation came to the fore — that the transition from a Mesolithic foraging economy to one based on farming was very rapid and more or less contemporaneous in the two regions. The evidence seemed particularly clear among coastal populations, where there was a marked shift in $\delta^{13}\text{C}$ to lighter values, which was interpreted as reflecting a fundamental change in dietary emphasis from marine to terrestrial resources (Bonsall, Anderson and Macklin 2002; Bonsall et al. 2002; Schulting and Richards 2002a; Richards, Schulting and Hedges. 2003; Fig. 26-1).

This view was challenged by Milner et al. (2004) who suggested that the stable isotope data were in conflict with other lines of evidence, thus provoking

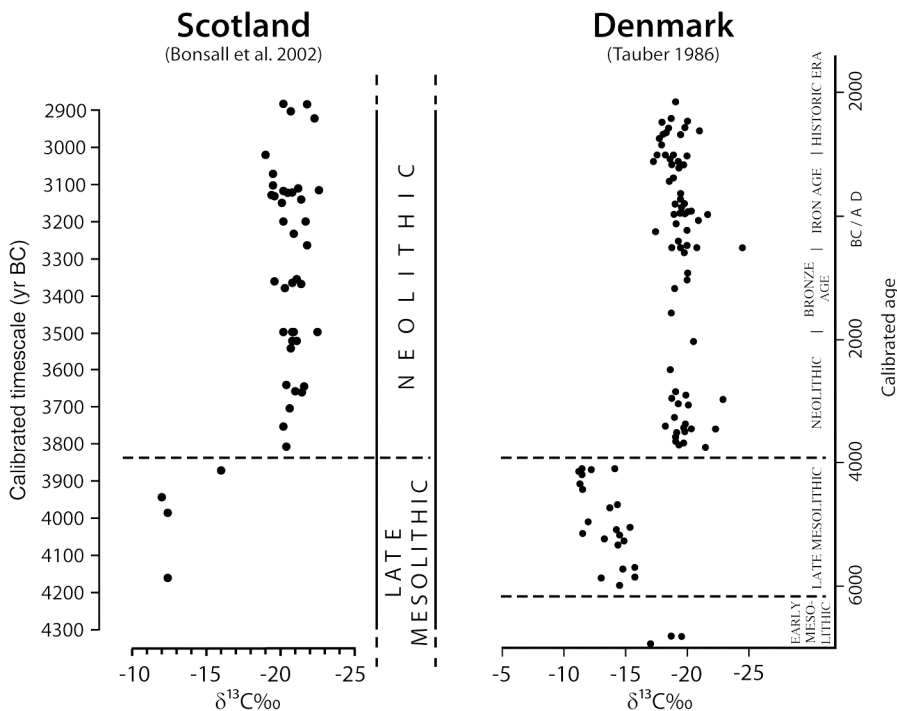


Fig. 26-1: Carbon stable isotope results for Late Mesolithic and Neolithic humans from Scotland and Denmark, as published by Bonsall et al. (2002) and Tauber (1986).

considerable debate (Hedges 2004; Lidén et al. 2004; Barbarena and Borrero 2005; Milner et al. 2006; Richards and Schulting 2006). The following discussion is a further contribution to the debate.

2. Discussion

2.1 The current debate

Milner et al. (2004), echoing concerns expressed by Meiklejohn, Brinch Petersen and Alexandersen (1988), raised three main objections to the notion of abrupt dietary change at the Mesolithic–Neolithic transition. They argued that, (i) previous interpretations of the stable isotope data conflicted with archaeological evidence for continued heavy use of marine resources in the Neolithic, particularly

in southern Scandinavia, (ii) the human samples analysed to date are unrepresentative of the original Mesolithic and Neolithic populations, and (iii) the dietary interpretations that had been placed on the stable isotope data by some previous authors were flawed. From a discussion of these issues they concluded that the dietary shift at the Mesolithic–Neolithic transition was not as extreme or rapid as had been claimed.

If we examine Milner et al.’s three main objections to the conventional view, the following points emerge:

Was there continued exploitation of marine resources in the Early Neolithic? This is beyond dispute, since there is widespread archaeological evidence of coastal exploitation by Neolithic communities in the form of shell middens, boats, and various kinds of fishing gear including traps and weirs (Meiklejohn, Brinch Petersen and Alexandersen 1988; Pedersen 1995; Bonsall, Anderson and Macklin 2002). However, their mere existence tells us nothing about the dietary importance of seafood in the period after c. 4000 cal BC.

Are the human remains available for analysis biased, and hence the stable isotope data based on these samples unrepresentative of Late Mesolithic and Early Neolithic populations? Any archaeological record is probably a biased reflection of past events. Most Final Mesolithic (c. 5000–4000 cal BC) human remains from Britain and southern Scandinavia are associated with coastal sites. The British sample is particularly small, deriving from one small island (Oronsay) off the west coast of Scotland, and hence may not be typical (cf. Bonsall, Anderson and Macklin 2002). However, the Neolithic sample is much larger and possibly more representative. Milner et al. (2004) argued that in Tauber’s (1981, 1986) seminal study of prehistoric diets in Denmark (Fig. 26-1b) most of the Mesolithic samples were from coastal sites while the Neolithic samples were mainly from inland sites, and therefore the differences in stable isotope values were not necessarily a fair reflection of dietary change at the transition. This is a valid criticism, but it is not necessarily applicable to other areas of northwest Europe. For example, in a study of the Mesolithic–Neolithic transition in Scotland (Bonsall, Anderson and Macklin 2002), the Neolithic samples considered were all from coastal sites (Fig. 26-1a) and show a comparable pattern to those observed at inland sites in Britain (Richards, Schulting and Hedges 2003) and southern Scandinavia (Tauber 1981; Richards, Schulting and Hedges 2003).

Are current interpretations of stable isotope data flawed? In palaeodietary studies, the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values for human bone collagen are the primary tools for interpretation. Marine and terrestrial organisms typically have quite different $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values, and these should be reflected in the consumer’s collagen. In

addition, $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values tend to increase as N and C are transferred up the food chain ('trophic enrichment'). Like all scientific theories, dietary reconstruction using the results of stable isotope analyses involves a series of assumptions. Milner et al. (2004), following Richards and Hedges (1999), list these as:

Human bone collagen composition reflects the diet averaged over 5–10 years prior to death;

Stable isotope ratios in human bone collagen only reflect the protein portion of the diet, and therefore the lipid and carbohydrate components are effectively 'invisible';

The offset between dietary protein and the consumer's bone collagen ('trophic enrichment') is 0–1‰ for $\delta^{13}\text{C}$ and c. 3‰ for $\delta^{15}\text{N}$;

Variations in the nutritional quality of the diet, and in particular the proportion of protein to carbohydrate, do not affect any of the above assumptions;

The dietary end-members, i.e. the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values that correspond to the extremes of a purely marine and a purely terrestrial diet, are approximately known.

In the context of this study, assumptions 2, 4 and 5 are the most critical. Considering assumptions 2 and 4, Ambrose and Norr (1993) have shown that in high protein diets the carbon in collagen comes primarily but not exclusively from protein. In contrast, for a low protein diet, both the lipids and carbohydrates will contribute significantly to the carbon in collagen. Consequently, since carbohydrate and lipids are depleted in ^{13}C relative to protein there is the potential to misinterpret the human dietary signal, particularly in low protein diets. Although, this observation derives from a laboratory study of rats, rats and humans have similar digestive physiologies and, therefore, the relationships between the isotopic composition of diet and bone collagen should be similar in the two species (Ambrose and Norr 1993, 28).

Milner et al. (2004) used this point to argue that Neolithic diets were much lower in protein than Mesolithic diets and that in such a diet a significant proportion of the small amount of protein could come from marine food without having a major influence on the $\delta^{13}\text{C}$ value of the human bone collagen.

Diet	Collagen $\delta^{13}\text{C}$ (‰)	Collagen $\delta^{13}\text{C}$ (‰)
	direct routing	scrambled routing
High protein, terrestrial	-19.6	-21.9
High protein, 20% marine	-17.8	-20.5
Low protein, terrestrial	-20.0	-21.6
Low protein, 20% marine	-18.2	-21.2

Table 26-1: Predicted human bone collagen $\delta^{13}\text{C}$ values for a range of hypothetical diets, based on contrasting biochemical pathways for incorporation of carbon into collagen (Hedges 2004, 36).

Hedges (2004) devised a simple mathematical model to illustrate this. The model describes two extreme scenarios: 1) ‘direct routing’ in which all of the carbon in human bone collagen comes from dietary protein, and 2) ‘scrambled routing’ in which the carbon in collagen is derived proportionately from the carbohydrate, lipid and protein components of the diet. The model was used to calculate the final human bone collagen $\delta^{13}\text{C}$ values for a range of diets using the two extreme scenarios described above (Table 26-1). Hedges was able to show that using the scrambled routing scenario, a hypothetical low protein diet, in which 20–30% of the protein is marine, produces a $\delta^{13}\text{C}$ value (-21.2‰) that is only slightly heavier than that of a 100% terrestrial diet (-21.6‰ for low protein, -21.9‰ for high protein). Hedges considered these scenarios to be extreme; however, they do illustrate the variation in stable isotope values resulting from contrasting biochemical pathways.

2.2 Modelling ancient diets

Hedges’ model can be refined in terms of, (i) the percentage carbon routing into collagen, which will depend on the protein content of the diet (‘partial routing’), (ii) the composition of the diet, and (iii) the stable isotope values of the main dietary components. In the following discussion, the actual data derived by Ambrose and Norr (1993) have been used to determine the carbon routing to bone collagen from protein and energy (carbohydrates + lipids) (Fig. 26-2). In addition, the food source stable isotope values and the diet to bone collagen enrichment factor employed by Hedges (2004) and Van der Merwe, Lee-Thorp and Raymond (1993) have been combined with our own empirical data for shellfish and used as the basis of the calculations (Table 26-2). Using this revised partial routing model, we have determined the $\delta^{13}\text{C}$ values that would result from a range of hypothetical diets.

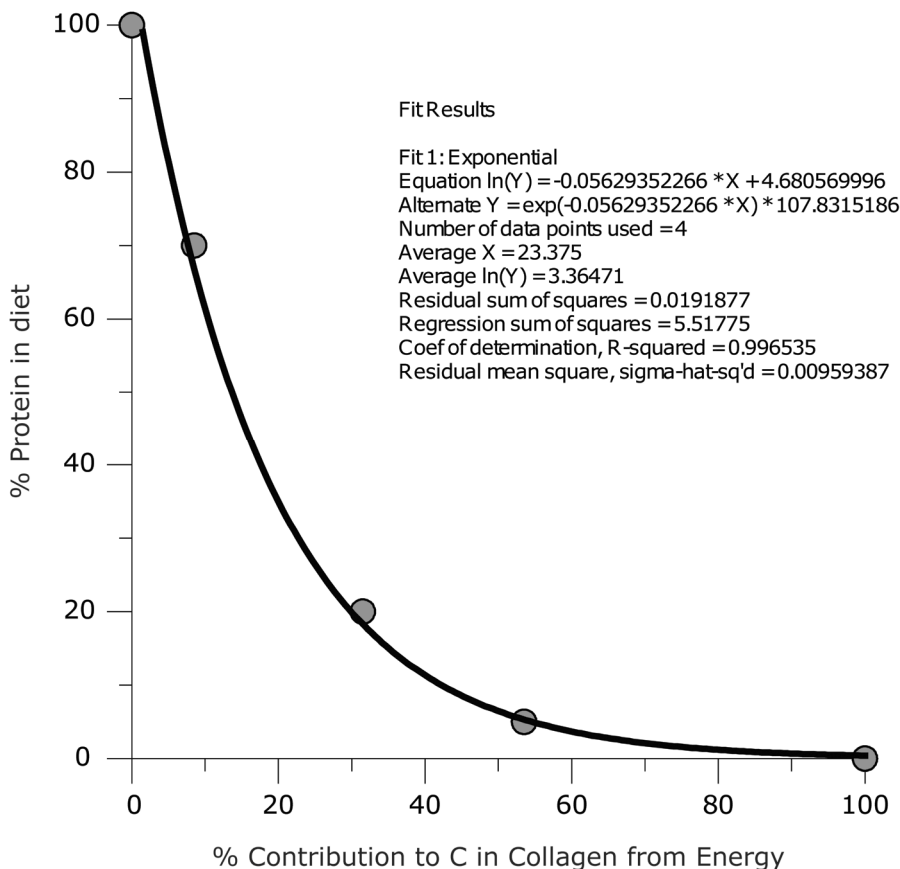


Fig. 26-2: Percentage contribution to carbon in collagen from energy sources (fats and carbohydrates) with varying percentages of protein in the diet (based on data in Ambrose and Norr 1993).

Table 26-3 presents a hypothetical ‘Neolithic diet’ based on terrestrial food sources. The nutritional data in this table have been derived from standard food composition tables (Paul and Southgate 1978). We regard this as a realistic average diet for a Neolithic agro-pastoral community, with 50% by weight being made up of cultivated cereals and pulses, 14% by wild plants, and 36% by animal (meat and dairy) products. It is worth noting that this is *not* the ‘low protein’ diet that Milner et al. (2004) have inferred for the Neolithic; it would provide a comparable amount and quality of protein to that recommended today for an active adult of average bo-

Food source	delta (‰)	change in delta (‰)
Terrestrial animal protein	-24	
Plant protein	-25	
Marine protein	-15	
Oyster/Mussel protein	-20	
Terrestrial animal fat	-29	
Plant fat	-30	
Marine fat	-21	
Plant carbohydrate	-26	
Oyster/Mussel fat	-26	
<i>Enrichment to collagen (terrestrial)¹</i>		4.5
<i>Enrichment to collagen (marine)²</i>		2.5

Table 26-2: Stable isotope values of the main dietary components and the diet–collagen enrichments used in the revised partial routing model employed in this paper. The values are taken from Hedges (2004, 36), with the exception of the shellfish protein values which are based on our own laboratory measurements (forthcoming).

dy weight (65kg). In terms of the proportions of protein, carbohydrates and fat, it also falls between the terrestrial diet extremes (12.5–53.3% protein) suggested by Hedges (2004, 36).

Starting from our standard Neolithic diet (Table 26-3) we then varied the protein components to produce the data contained in table 26-4. Performing the model calculation on the individual diets shown in table 26-4 produces the collagen $\delta^{13}\text{C}$ values shown in table 26-5.

The data presented in table 26-5 suggest that a 100% terrestrial diet can have $\delta^{13}\text{C}$ values ranging between -21.5‰ for a diet consisting entirely of plant foods (vegan) to -20.1‰ for a diet consisting wholly of animal products (e.g. some pastoralists). It follows that any human bone collagen $\delta^{13}\text{C}$ value that is lighter than ca. -20.0‰ could be indicative of a purely terrestrial diet. Table 26-5 also illustrates how the inclusion of marine foods in the diet tends to result in heavier $\delta^{13}\text{C}$ values, but also that the effect varies according to the food source. For example, certain types of shellfish (essentially the filter-feeding bivalves) that are known to have been heavily exploited by Late Mesolithic and Neolithic groups in north-west Europe tend to have lighter $\delta^{13}\text{C}$ values than other marine animals. Our laboratory analyses of oyster (*Ostrea edulis*) and mussel (*Mytilus edulis*) flesh (defatted) give average $\delta^{13}\text{C}$ values that are 2–5‰ lighter than those for molluscan

	Weight (g)	Kcal	Protein (g)	CH (g)	Fat (g)
Meat (grilled)	100	200	27.0	0	16.0
Cereal (boiled, i.e. gruel)	500	600	13.5	138.0	3.0
Bread (wholemeal)	200	432	17.6	83.6	5.4
Pulses (boiled)	200	104	10.0	15.4	0.8
Seakale (boiled)	100	8	1.4	0.6	0
Milk (cow's)	500	325	16.5	23.5	19.0
Cheese	50	150	11.4	0	12.6
Hazelnuts	50	190	3.8	3.0	18.0
Fruit	100	29	7.6	6.0	0.0
Total (animal foods)	650	675	54.9	23.5	47.6
Total (plant foods)	1150	1363	53.9	247.4	27.2
TOTAL	1800	2038	108.8	270.9	74.8
%			23.9%	59.6%	16.5%

Table 26-3: Hypothetical daily 'Neolithic' diet based on terrestrial food sources.

Diet	Plant:Animal:Marine protein (%)	Protein (%)	CH (%)	Fat (%)
Neolithic (100% C ₃ plant protein)	100:0:0	16.4	75.2	8.4
Neolithic (100% animal protein)	0:100:0	43.5	18.7	37.8
Neolithic standard (50:50 C ₃ plant/animal)	50:50:0	23.9	59.7	16.5
Neolithic standard diet + marine protein	45:45:10	25.8	58.0	16.2
	40:40:20	28.0	56.1	15.8
	35:35:30	30.7	53.8	15.5
	30:30:40	34.0	51.0	15.0
	25:25:50	38.0	47.6	14.4
	20:20:60	43.2	43.2	13.6
	15:15:70	49.9	37.4	12.7
	10:10:80	59.1	29.6	11.3
	5:5:90	72.5	18.1	9.4
	0:0:100	93.8	0	6.3

Table 26-4: Composition of hypothetical diets with varying amounts of marine protein (cf.

Table 26-5). Column 2 shows the proportions (by weight) of plant, animal and marine protein in the diets. Columns 3–5 show the proportions (by weight) of protein, carbohydrate and fat from all sources.

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Diet		A	B
Neolithic standard		-20.9	-20.9
Neolithic (100% C ₃ plant protein)		-21.5	-21.5
Neolithic (100% animal protein)		-20.1	-20.1
Neolithic standard diet + MARINE	0%	-20.9	-20.9
	10%	-20.1	-20.3
	20%	-19.3	-19.7
	30%	-18.5	-19.1
	40%	-17.6	-18.4
	50%	-16.6	-17.6
	60%	-15.6	-16.8
	70%	-14.6	-16.0
	80%	-13.4	-15.0
	90%	-12.1	-13.9
	100%	-10.4	-12.4
Neolithic standard diet + OYSTER	0%	-20.9	-20.9
	10%	-20.5	-20.7
	20%	-20.1	-20.3
	30%	-19.7	-20.2
	40%	-19.2	-20.0
	50%	-18.7	-19.7
	60%	-18.2	-19.4
	70%	-17.7	-19.1
	80%	-17.1	-18.7
	90%	-16.4	-18.2
	100%	-15.4	-17.3

Table 26-5: Predicted human bone collagen $\delta^{13}\text{C}$ values for a series of hypothetical diets with varying proportions of protein from major food sources. A – enrichment of 4.5‰ from diet to collagen for all food types; B – enrichment from diet to collagen of 4.5‰ for terrestrial foods and 2.5‰ for marine foods.

herbivores (e.g. limpets and periwinkles) and carnivores (e.g. whelks), crustaceans, and pelagic fish like cod.

On the basis of our calculations (Table 26-5, column A) the inclusion of 10% protein from mussels and/or oysters in our standard Neolithic diet would result in a $\delta^{13}\text{C}$ value that is <0.5‰ heavier than a purely terrestrial diet. Our results also show that mussels and oysters have relatively low $\delta^{15}\text{N}$ values, in the range 4.5–5.5 for mussels and 7.0–8.5 for oysters. These values are similar to those of terrestrial

mammalian herbivores, reflecting their corresponding positions in the respective food chains. From this, it follows that the inclusion of filter-feeding molluscs in the diet would have a negligible impact on human bone collagen $\delta^{15}\text{N}$ values.

The data presented in table 26-5 (column A) suggest that oysters could contribute as much as 20% of dietary protein before the $\delta^{13}\text{C}$ value of human bone collagen becomes heavier than -20‰ and therefore 'suggestive' of a marine component in the diet.

The above discussion assumes a uniform diet–collagen shift in $\delta^{13}\text{C}$ of 4.5‰. However, some studies suggest that the difference in $\delta^{13}\text{C}$ between flesh and bone of marine fish is less than that recorded in many terrestrial mammals (e.g. Van der Merwe, Lee-Thorp and Raymond 1993, 84-86), which would imply a diet–human bone collagen shift of less than 4.5‰ for a fish-based diet. Ultimately, this would result in the marine fish component of the diet having a smaller effect on human bone collagen $\delta^{13}\text{C}$ values than indicated in table 26-5 (column A), i.e. the resulting $\delta^{13}\text{C}$ values for diets with a marine fish component would be lighter. Calculations based on a 2.5‰ shift in the marine portion of diet are included for comparison (Table 26-5, column B). The 100% marine diet end members of -10.4 and -12.4‰ are both credible. For example, Arneborg et al. (1999) used a marine end member of -12.5‰ based on bone collagen stable isotope analysis of a population of Greenland Inuit who were assumed to have a 100% marine diet. Equally, $\delta^{13}\text{C}$ values that are significantly heavier than -12.5‰ have been recorded for Mesolithic individuals from north-west Europe (Fig. 26-4).

2.3 Archaeological implications

A further observation that can be made from these data is that the differential between a 50% oyster diet and 50% general marine diet is >2‰. This would have implications for calibration of radiocarbon dates derived from human bone collagen where, on the basis of the $\delta^{13}\text{C}$ value, there is a significant marine component in the diet. If we assume dietary end members of -20.9‰ for a terrestrial diet and -10.4‰ for a 100% marine diet, then on the basis of a linear interpolation between these values, our 50% oyster diet would appear to correspond to a 21% marine diet. This would lead to a misinterpretation of the marine component for purposes of adjusting for the *marine reservoir effect* (MRE) during the radiocarbon age calibration process. In other words, two individuals, one of whom has a 50% oyster diet and one a 50% general marine diet, would show the same MRE in their ^{14}C ages, but significantly different bone collagen $\delta^{13}\text{C}$ values, which would affect the calibration of the radiocarbon ages to calendar

ages.

Figure 26-3 shows the $\delta^{13}\text{C}$ values for radiocarbon-dated Late Mesolithic and Neolithic (c. 6000–4000 BP / 4900–2550 cal BC) skeletons from coastal sites in Great Britain. These data are taken from Milner et al. (2004, electronic appendix) but with some additions (Bonsall, unpublished data). The great majority of the Neolithic samples have $\delta^{13}\text{C}$ values of between -20‰ and -22‰. Based on our calculations (cf. Table 26-5) this suggests a very small marine input to diet, unless the marine component was from ‘filter-feeding’ molluscs. A small proportion of the Neolithic samples have $\delta^{13}\text{C}$ values that are heavier than -20‰, which implies a significant marine input to diet, particularly so if the marine component consisted primarily of filter-feeding molluscs (cockles, mussels, oysters, etc.).

The values for Late Mesolithic humans are significantly heavier (-12 to -16‰) with three samples suggesting a very heavy reliance on marine resources. However, these four results derive from two sites on Oronsay in the Inner Hebrides, a very small offshore island with limited terrestrial resources. If these individuals were resident on the island year round (which is currently the source of some debate: cf. Bonsall 1996; Mithen 2000; Mellars 2004) then it is possible that they were more heavily dependent on marine resources than contemporaneous populations on larger islands or the west Scottish mainland, in which case the contrast in diet between the Late Mesolithic and Early Neolithic populations of Great Britain suggested by figure 26-3 may be exaggerated. Until more Late Mesolithic human remains become available for analysis, the extent of any dietary shift at the Mesolithic–Neolithic transition in Great Britain remains an open question. However, it is worth pointing out that all radiocarbon dated Mesolithic skeletons from coastal sites in Great Britain for which stable isotope data exist have significantly heavier $\delta^{13}\text{C}$ values than any dated Early Neolithic skeletons. The lightest Mesolithic $\delta^{13}\text{C}$ value recorded from a coastal site in Great Britain (-18.5‰) is from Paviland Cave on the Gower peninsula of South Wales dated to 7190±80 BP (OxA-681; Schulting and Richards 2002b), and if this individual’s diet included significant quantities of filter-feeding molluscs (which are abundant along the Gower coast) the contribution of marine resources to diet could have been much greater than the $\delta^{13}\text{C}$ value implies.

Previous suggestions of an abrupt dietary shift at the Mesolithic–Neolithic transition in southern Scandinavia, reflected in human bone collagen $\delta^{13}\text{C}$ measurements (e.g. Mays 1998; Bonsall et al. 2002; Schulting and Richards 2002a; Richards, Schulting and Hedges 2003), have relied on Tauber’s (1981) study of prehistoric skeletons from Denmark. Milner et al. (2004) pointed out that this interpretation did not take into account the fact that Tauber’s data came from a

Great Britain

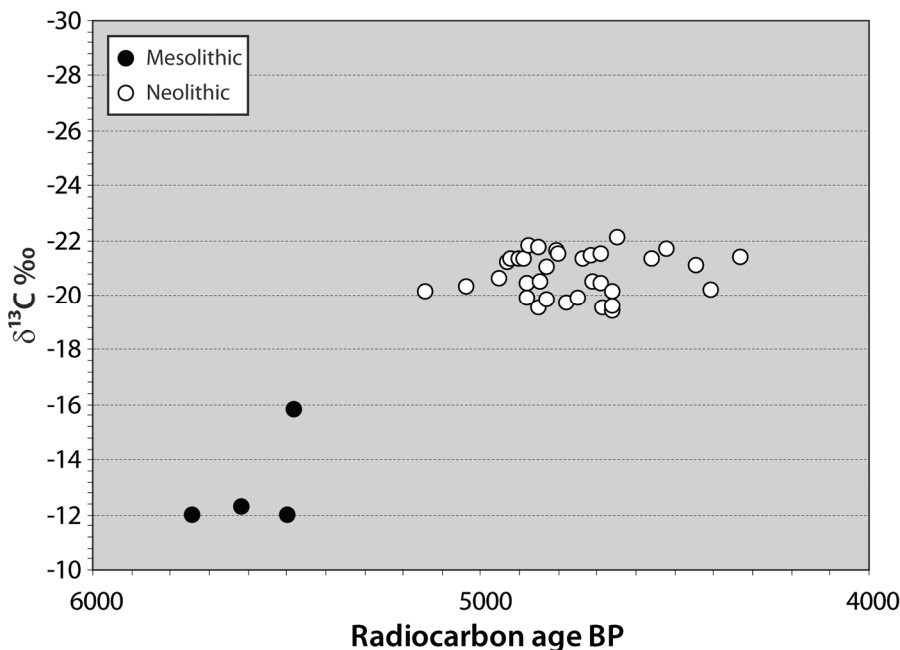
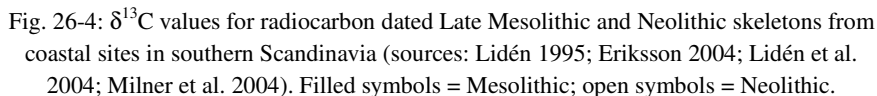


Fig. 26-3: $\delta^{13}\text{C}$ values for radiocarbon dated Late Mesolithic and Neolithic skeletons from coastal sites in Great Britain.

geographically restricted area and that most of the Neolithic samples were from inland sites while the Mesolithic samples were mainly from coastal sites. Since 1981 more data have become available not only for Denmark, but also southern Sweden including a number of sites on the Baltic Sea coast. Using these Scandinavian data, Lidén et al. (2004) have argued that in southern Scandinavia there was no sharp division between Late Mesolithic and Early Neolithic diets, and by extension have challenged “the idea of a general European dietary transition from marine resources during the Mesolithic to terrestrial resources during the Neolithic” (Lidén et al. 2004, 23).

Figure 26-4 shows the $\delta^{13}\text{C}$ values for directly dated Late Mesolithic and Neolithic (c. 6000–4000 BP / 4900–2550 cal BC) skeletons from coastal sites in southern Scandinavia. The trends appear more complex than the British situation, with a significant overlap in the ranges of the $\delta^{13}\text{C}$ values between Late Mesolithic and



While the majority of Late Mesolithic skeletons from Area A have $\delta^{13}\text{C}$ values in the range -14 to -11‰, consistent with marine-based diets, individuals from two

sites have significantly lighter values. The individual with a value of -16.5‰ is from the site of Ertebølle on the Limfjord in northern Jutland, where there is evidence of intensive exploitation of filter-feeding molluscs (primarily *Ostrea edulis*) in the Late Mesolithic (Andersen and Johansen 1986). If oysters were the dominant marine food source for this individual, then the contribution of marine resources to the diet could have been much greater than the $\delta^{13}\text{C}$ value would otherwise suggest. An individual from the site of Skateholm III in Scania has a $\delta^{13}\text{C}$ value of -18.6‰. While this value might suggest a lower reliance on marine resources than other Late Mesolithic skeletons from the region and a correspondingly greater contribution to diet from terrestrial resources, it could equally reflect heavy consumption of freshwater fish (e.g. pike [*Esox lucius*] and perch [*Perca fluviatilis*]) which were abundant in the neighbouring sites of Skateholm I and II (Larsson 1988). This interpretation is supported by the $\delta^{15}\text{N}$ value of +13.8‰ for the Skateholm III skeleton (Milner et al. 2004, electronic appendix) which is unusually high for a diet based on terrestrial resources, but comparable to values recorded for Mesolithic populations from the Iron Gates section of the Danube Valley where a dietary pattern based on freshwater fish is well documented (Bonsall et al. 1997).

The Neolithic samples from Area A also show an interesting pattern of variation. One sample shows a strongly marine signature in both $\delta^{13}\text{C}$ (-14.0‰) and $\delta^{15}\text{N}$ (+16.6‰). This comes from Evensås, a small island off the west coast of Sweden, in the more open marine environment of the Skagerrak. The skeleton was directly dated at 5010 ± 75 BP, which apparently places it around the time of the Mesolithic–Neolithic transition. However, the heavy $\delta^{13}\text{C}$ value means that a marine reservoir correction (probably c. 300 years) has to be applied, which would place the true age of the sample firmly in the Neolithic time-range at c. 4700 BP (3400 cal BC). Not only is this site on a small offshore island, it also lies within a coastal region of predominantly thin stony soils (leptosols) (Jones, Montanarella and Jones 2005, 48) with very limited agricultural potential. Therefore, the marine signal for this individual is not surprising. It could be argued that a reservoir correction should also be applied to the Mesolithic samples with heavy $\delta^{13}\text{C}$ values. Meiklejohn, Brinch Petersen and Alexandersen (1988, 204) assumed a reservoir correction based on 400 years ($\Delta R = 0$) for a 100% marine diet, which would result in a temporal overlap between the latest Mesolithic and earliest Neolithic skeletons. However, the sites in question lie mainly within the Baltic Sea basin and the size of the reservoir correction within the Baltic is difficult to estimate owing to a lack of data for calculating ΔR values for this region. Eriksson (2004, 152) has provided some evidence to suggest a much smaller reservoir effect for the waters around Gotland in the Middle Neolithic. If this were applicable to the Baltic as a whole during the middle Holocene, it would certainly narrow or

eliminate the temporal gap between the latest Mesolithic and the earliest Neolithic samples apparent in figure 26-4, but would not necessarily result in a significant temporal overlap.

Only two samples from Area A fall clearly within the Early Neolithic time-range (5150–4800 BP / 3950–3550 cal BC). It is interesting that these have very light $\delta^{13}\text{C}$ values, similar to the majority of the dated Neolithic skeletons from coastal areas of Great Britain (cf. Fig. 26-3), suggesting diets that were heavily reliant on terrestrial resources. In contrast to these earliest Neolithic samples, the great majority of skeletons dated between c. 4800 and 4100 BP (3550–2650 cal BC, ‘Middle’ Neolithic) show heavier $\delta^{13}\text{C}$ values (-20 to -17‰), which implies greater use of marine resources (although a small part of the increase in $\delta^{13}\text{C}$ could be the result of a growth in animal husbandry/dairying — cf. Table 26-5). Many of these skeletons are from sites on the Danish islands and in Scania, i.e. within the Baltic Sea basin, which is a brackish system with lower species diversity and a less complex foodweb compared to the more saline, oxygen-rich North Sea (Sandberg et al. 2000). The lack of large shell middens at coastal sites in the Baltic suggests that shellfish were not a major food source for Late Mesolithic and Early Neolithic populations, and thus the enrichment in $\delta^{13}\text{C}$ probably comes largely from the exploitation of fish and/or sea mammals.

In Area B paired ^{14}C and stable isotope measurements for Neolithic coastal populations are available for four sites (Carlsjögen, Ingelstorp, Ramshög and Tågarp) on the mainland of southeast Scania and one site (Resmo) on the island of Öland (Lidén 1995; Lidén et al. 2004). The ^{14}C ages of these samples range between c. 4550 and 4150 BP, and the $\delta^{13}\text{C}$ values from -19.5 to -17.2‰. The $\delta^{13}\text{C}$ average of -18.5‰ is heavier than that for Area A (-19.5‰, or -19.8‰ if only the ‘Baltic’ sites¹ are considered), which implies a greater use of marine resources by Neolithic coastal populations in Area B compared to Area A.

Currently, there is only one sample with paired ^{14}C and stable isotope measurements from a Mesolithic coastal site in Area B. This is from Alby on Öland (Königsson et al. 1993), with a ^{14}C age of 5260±70 BP (Ua-2333). The $\delta^{13}\text{C}$ value of -15.4‰ is significantly heavier than any seen in Neolithic coastal populations on Öland or the southeast Swedish mainland, and suggests a much greater marine input to diet. If Alby were representative of the dietary pattern among Late Mesolithic² coastal populations in Area B, then the evidence would imply a step-shift in diet at the Meso–Neolithic transition in this part of southern Scandinavia, paralleling that in Denmark/south-west Sweden and Great Britain. However, like Oronsay in Great Britain, for the moment Alby is an ‘isolated’ case, and more Late Mesolithic (and Early Neolithic) data are needed before the dietary

trends in Area B can be confirmed.

Discussion of the transition in Area C is constrained by a lack of data for the Late Mesolithic and Early Neolithic. The earliest samples for which paired ^{14}C and stable isotope measurements are available come from Middle Neolithic (Pitted Ware Culture) burials at Korsnäs in Södermanland (Fornander 2006) and Västerbjers on Gotland (Eriksson 2004). At Korsnäs bones from four or five adult individuals gave ^{14}C ages between c. 4540 and 4320 BP, while the ^{14}C ages for eight of the burials from Västerbjers range from c. 4370 to 4125 BP. The $\delta^{13}\text{C}$ values for these individuals (Korsnäs, $-15.2 \pm 0.79\text{‰}$; Västerbjers, $-14.8 \pm 0.43\text{‰}$) suggest a diet that was dominated by marine foods, though whether the $\delta^{13}\text{C}$ evidence reflects a near total reliance on seal hunting, as suggested by Eriksson (2004), is questionable. The $\delta^{13}\text{C}$ values for these two Middle Neolithic sites are similar to those from Late Mesolithic Alby on Öland in Area B (Fig. 26-4). Lidén et al. (2004) interpreted this as evidence against a general trend toward increased consumption of terrestrial resources in the Neolithic of southern Scandinavia. However, in view of the lack of comparative data for the Late Mesolithic and Early Neolithic of Gotland and the Baltic coast of Middle Sweden, it is premature to assume there was no dietary change, however small, at the Meso-Neolithic transition in Area C. On the evidence available, the possibility of a greater input from agriculture in the Early Neolithic (where land resources permitted) and subsequent reversion to a predominantly marine diet in the Middle Neolithic cannot be excluded.

Lidén et al. (2004) saw the greater use of marine resources in Neolithic southern Scandinavia compared to Great Britain as ‘culturally determined’. While regional variations in subsistence patterns could arise through differences in social history, it is also evident from the stable isotope data that there is a progressive increase in the average $\delta^{13}\text{C}$ values of regional Neolithic populations across north-west Europe from Great Britain to Gotland (Fig. 26-5), which suggests that environmental factors were involved. Van Klinken, van der Plicht and Hedges (1994; see also Richards and van Klinken 1997) found a degree of latitudinal and longitudinal variation in the $\delta^{13}\text{C}$ ratio of archaeological botanical and bone samples across Europe, which they linked primarily to the effect of climatic factors on carbon fractionation. Their data show only a very small difference in $\delta^{13}\text{C}$ between bone samples from Great Britain and southern Scandinavia, and so this is unlikely to be the whole explanation for the pattern of $\delta^{13}\text{C}$ variation observed in figure 26-5.

However, two climate-related factors that may help to explain the $\delta^{13}\text{C}$ data are growing season length and sea conditions. The length of the growing season is an

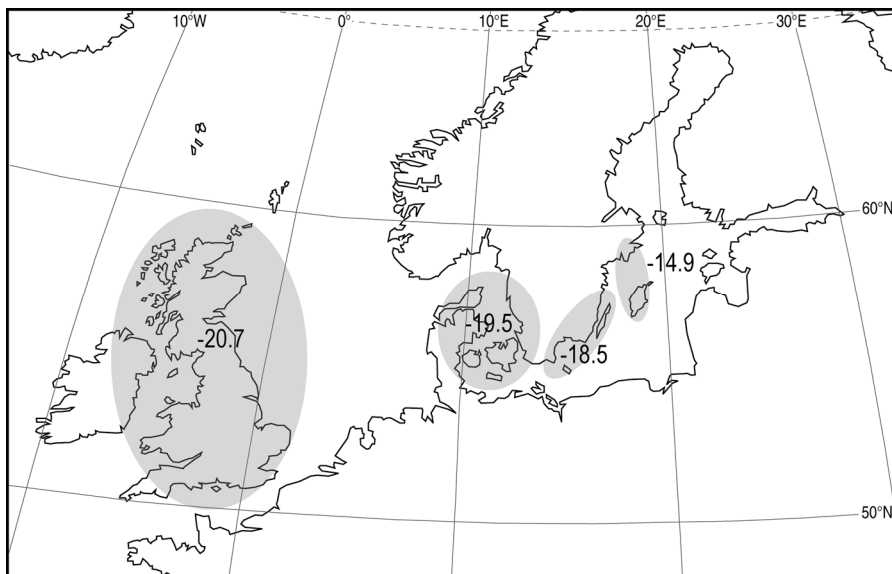


Fig. 26-5: Variation in mean bone collagen $\delta^{13}\text{C}$ values for Neolithic populations in north-west Europe.

important determinant of agricultural potential and productivity, and there is a broad correlation between the trend in the Neolithic $\delta^{13}\text{C}$ data (Fig. 26-5) and variation in average growing season length across northwest Europe. In very general terms, the growing season is longest in the British Isles where winters are milder, and becomes shorter toward the east and north.³ Growing season length also impacts on soil productivity. It follows that spatial and temporal variations in growing season length within north-west Europe would have had a significant impact on the sustainability of early agriculture, although growing season length would of course interact in a complex way with local soil variability to result in differences in land use potential. The generally rougher sea conditions around the British Isles may have imposed more limitations on offshore fishing (and beachcombing on exposed coasts) and entailed greater physical risks than in the more protected environments of the Baltic and the Limfjord.⁴ Thus sea conditions and growing season length place limitations on marine exploitation and farming, respectively, and they are likely to have been among the factors that influenced the subsistence choices exercised by people in the Neolithic.

3. Conclusions

Our review of the human bone collagen stable isotope evidence from north-west Europe re-affirms that there was a general shift from a marine- to a land-based diet at the Mesolithic–Neolithic transition in coastal areas of both Britain and southern Scandinavia, although local and regional variations are apparent. A step-change in average $\delta^{13}\text{C}$ values is evident among coastal populations across much of the region reflecting the rapid introduction of farming, but the magnitude of the change diminishes eastwards as the proportion of seafood in Neolithic diets increases. The reasons underlying this trend can be debated, but it is likely that environmental factors played at least some part, and further work is planned to investigate the interaction of climate and soils in this context. There were also ‘Neolithic’ communities living in areas of very limited agricultural potential (e.g. parts of western Sweden) who continued to rely heavily on marine resources. The few Late Mesolithic individuals from Denmark and western Scania whose $\delta^{13}\text{C}$ values approach or overlap those obtained from Neolithic skeletons in the same area can be explained in terms of heavy consumption of marine bivalves or freshwater fish.

Our empirical and model data also indicate that there is the potential to underestimate the proportion of seafood in a diet when it is based solely on the measurement of the $\delta^{13}\text{C}$ value of human bone collagen. The data suggest that for a given marine system the consumption of bivalves will have less effect on the $\delta^{13}\text{C}$ value compared to the equivalent consumption of fish and/or marine mammals. This also has important chronological implications as the $\delta^{13}\text{C}$ value is taken as a measure of the percentage marine diet and used as a factor in the calibration of conventional radiocarbon ages into calendar age ranges. Thus, heavy consumption of marine bivalves could lead to underestimation of the marine reservoir contribution to the ^{14}C age of human bone samples when estimation is based on the $\delta^{13}\text{C}$ values of the human bone collagen.

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Notes

¹ Excluding sites on the Limfjord, Kattegat, and Skagerrak.

² Lidén (1995) accepted the Alby burial as ‘Mesolithic’, while Lidén et al. (2004) described it as ‘Late Mesolithic/Early Neolithic’. The heavy $\delta^{13}\text{C}$ value means that a marine reservoir correction has to be applied to the ^{14}C date, which would make the true age of the sample younger. Eriksson (2004) calculated the age offset caused by the marine reservoir effect for Middle Neolithic Gotland as 70 ± 40 years. If a similar offset were applied to Alby it would give a reservoir corrected age of ca. 5200 BP (4000 cal BC) — arguably, still within the Late Mesolithic time-range for the region.

³ Growing season is defined as the part of the year with daily mean temperatures above 5°C. This varies considerably with latitude, longitude, and altitude. In the UK, between 1961 and 1991, average growing season length was 252 days. In Middle Sweden during the same period the average was less than 200 days.

⁴ On average, storm events in the Baltic are less frequent, of shorter duration, and with lower wave height compared to the Atlantic and North Sea (see, e.g., Weisse, von Storch and Feser 2005; Broman et al. 2006; Soomere and Zaitseva 2007).